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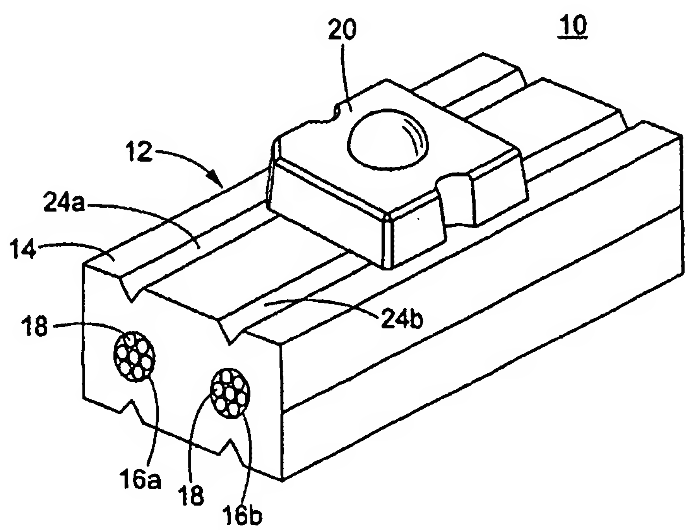
(54) Title: ILLUMINATED SIGNAGE EMPLOYING LIGHT EMITTING DIODES



(57) Abstract: An illuminated sign (88) includes a flexible electrical power cord (100) including first and second parallel conductors (112, 114)surroundingly contained within an insulating sheath defining a constant separation distance between the parallel conductors (112, 114). A plurality of light emitting diode (LED) devices (102) are affixed to the cord (100). Each LED device (102) includes an LED (104) having a positive lead (130p) electrically communicating with the first parallel conductor (112) and a negative lead (130p) electrically communicating with the second parallel conductor (114). A stencil (92) defines a selected shape, and the electrical cord (100) is arranged on the stencil (92). Power conditioning electronics (210, 220) disposed away from the stencil (92) electrically communicate with the first and second parallel conductors (112, 114) of the electrical power cord (100). The power conditioning electronics (210, 220) power the LED devices (102) via the parallel conductors (112, 114).

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ILLUMINATED SIGNAGE EMPLOYING LIGHT EMITTING DIODES

This application claims priority from U.S. Non-provisional Patent Application Serial No. 09/866,581 filed on May 25, 2001.

BACKGROUND OF THE INVENTION

Channel letters are known to those skilled in the art of making commercial signs as the most attractive and expensive form of sign lettering. Briefly, channel letters usually include a plastic or metal backing having the shape of the letter to be formed. Metal channel siding, frequently formed of aluminum with a painted or otherwise finished interior and exterior surface, is attached to and sealed to the letter backing, giving depth to the letter to be formed. Electrical lighting fixtures, such as neon tubing and mounting brackets, are attached to the letter backing. Typically, a colored, translucent plastic letter face is attached to the front edge portion of the channel side material.

As discussed above, neon lighting is typically incorporated into channel lettering systems. Neon systems are very fragile and, therefore, tend to fail and/or break during manufacture, shipping or installation. Also, such lighting systems use high voltage (e.g., between about 4,000 and about 15,000 volts) electricity to excite the neon gas within the tubing. High voltage applications have been associated with deaths by electrocution and building damage due to fire. Semiconductor lighting (e.g., light emitting diodes), that overcomes most of these drawbacks, has been used for channel lettering.

One such conventional channel lettering device attaches a light emitting diode ("LED") system to a back of a channel letter such that the LED system emits light toward a translucent face at a front of the device. The LEDs are spaced at regular intervals (e.g., 2 inches) and are pressed into a socket. The socket is designed for a press-fit of a modified Super Flux (Piranha) package. The lead frames of the Piranha are bent 90 degrees to fit into the socket. The connection for the LED is similar to insulation displacement ("IDC"). The socket also has two IDC places for a red and black wire. This system puts all of the LEDs in parallel. Furthermore, the two part power supply (Initial (120VAC to 24VDC) and the Secondary (24VDC to ~2.3VDC)) have two basic wiring connections. The secondary has a sense circuit, which has one LED attached for determining the voltage applied to the rest of the LEDs that are attached to the second connection.

Another conventional channel lettering device attaches to a side of the channel letter and is pointed toward the backing. The diffuse surface of the channel letter walls provides a uniform appearance. Each module has a predetermined number of LEDs electrically connected in series. Furthermore, all of the modules are daisy chained together in a parallel circuit. The LEDs are mounted on an aluminum base for heat sinking purposes.

Another conventional channel lettering device uses a plurality of surface mounted LEDs with an integral connector system.

Although these conventional LED channel lettering systems overcome some of the drawbacks associated with neon systems, other shortcomings are evident. For example, the conventional LED channel lettering systems offer only limited flexibility. More specifically, the LEDs cannot be easily set into a desired shape involving significant curves or bends (e.g., wrapped around a pole or in a very small radius (<3 inches). Furthermore, the LEDs cannot be easily moved from one lighting application to another.

The present invention contemplates an improved apparatus and method that overcomes the above-mentioned limitations and others.

BRIEF SUMMARY OF THE INVENTION

In accordance with one embodiment of the present invention, an illuminated sign is disclosed. A flexible electrical power cord includes first and second parallel conductors surroundingly contained within an insulating sheath defining a constant separation distance between the parallel conductors. A plurality of light emitting diode (LED) devices are affixed to the cord. Each LED device includes an LED having a positive lead electrically communicating with the first parallel conductor and a negative lead electrically communicating with the second parallel conductor. A stencil defines a selected shape and onto which the electrical cord is arranged. Power conditioning electronics disposed away from the stencil electrically communicate with the first and second parallel conductors of the electrical power cord. The power conditioning electronics power the LED devices via the parallel conductors.

In accordance with another embodiment of the present invention, an article of manufacture is disclosed for installing a plurality of light emitting diodes (LEDs) into a channel letter housing which has at least one light-transmissive surface. A substantially rigid structure is pre-formed or formable for arrangement in the channel letter housing. A flexible cable including at least two flexible parallel conductors is arranged to support an electrical potential difference between the parallel conductors. A plurality of LEDs electrically parallel-interconnected by communication of the anode and cathode of each LED with the at least two conductors of the flexible cable. A fastener secures at least a portion of the flexible cable onto the rigid structure. A power module receives power having first characteristics and converts the received power to a supply power having second characteristics which is communicated to the at least two conductors of the flexible cable to power the plurality of parallel-interconnected LEDs.

In accordance with another embodiment of the present invention, a light emitting diode (LED) light engine is disclosed. An electrical cable includes at least two flexible electrical conductors. The electrical cable further includes a flexible, electrically insulating covering that surrounds the electrical conductors.

The conductors are arranged substantially parallel with a selected separation therebetween. An LED with a plurality of electrical leads separated by the selected separation electrically contacts the electrical conductors and mechanically pierces the insulating covering to mechanically secure the LED to the electrical cable.

In accordance with another embodiment of the present invention, a light emitting diode (LED) light engine is disclosed. An electrical cable includes a positive flexible conductor connected with an associated positive source of electrical power, a negative flexible conductor connected with an associated negative source of electrical power, and an electrically insulating covering surrounding and electrically insulating the positive and negative conductors and holding the conductors separate at a selected separation distance. An LED includes positive and negative leads. A connector mechanically secures to the flexible insulating covering. The connector includes positive and negative prongs that pierce the insulating covering and electrically contact the positive and negative conductors, respectively. The connector further has the LED mounted thereon with the positive and negative leads of the LED electrically contacting the positive and negative prongs, respectively.

In accordance with another embodiment of the present invention, a method of manufacturing an LED light engine is provided. A plurality of conductive elements are insulated to form a flexible electrically insulating conductor. An LED is mechanically secured to the insulated conductive elements. Simultaneously with the mechanical securing, a plurality of leads of the LED are electrically contacted to respective ones of the conductive elements.

In accordance with yet another embodiment of the present invention, a flexible lighting device is disclosed. A flexible cable includes an electrically insulating sheath which contains positive and negative conductors electrically isolated from one another. The sheath provides a spacing between the positive and negative conductors. A plurality of light emitting diode (LED) devices are spaced apart from one another on the cable. Each of the LED devices has an LED including positive and negative leads mounted on a connector which

mechanically secures the LED device to a portion of the flexible cable and electrically connects the positive and negative LED leads to the positive and negative conductors through positive and negative conductive piercing members which pierce the sheath to make electrical contact with the respective conductors.

In accordance with still yet another embodiment of the present invention, a light emitting diode (LED) lighting apparatus is disclosed. A flexible electrical cable includes an anode wire and a cathode wire arranged in an electrically isolating sheath. A plurality of LED devices are spaced apart along the cable and mechanically and electrically connect therewith. Each LED device includes an LED having at least one anode lead and at least one cathode lead. Each LED device further includes a connector with an LED socket that receives the anode and cathode leads. The LED socket mechanically retains the LED. The connector further includes a first electrically conductive path between the anode lead and the anode wire, and a second electrically conductive path between the cathode lead and the cathode wire. The first and second conductive paths displace portions of the cable sheath.

One advantage of the present invention resides in providing a channel lettering having a reduced number of parts compared with past systems.

Another advantage of the present invention resides in the use of parallel interconnection of the LEDs which reduces the likelihood that a failed LED will adversely affect performance of other LEDs on the same electrical circuit.

Another advantage of the present invention resides in the locating of the conditioning electronics away from the channel lettering, e.g. in a secure and weatherproofed interior location.

Another advantage of the present invention is the avoidance of soldering connections in the flexible LED light engine.

Yet another advantage of the present invention is that it allows for coupling in the electrical power anywhere along the flexible LED light engine.

Still yet another advantage of the present invention resides in its modular nature which allows part or all of a channel lettering to be constructed on-site in a customized manner.

Numerous advantages and benefits of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating a preferred embodiment and are not to be construed as limiting the invention.

FIGURE 1 illustrates an LED light engine according to a first embodiment of the present invention.

FIGURE 2 illustrates a perspective view of the LED shown in FIGURE 1.

FIGURE 3 illustrates an exploded view of an LED connector within a light engine according to a second embodiment of the present invention.

FIGURE 4 illustrates a cross-sectional view of the connector of the second embodiment.

FIGURE 5 illustrates a splice connector according to the present invention.

FIGURE 6 illustrates an exploded view of the splice connector shown in FIGURE 5.

FIGURE 7 illustrates the light engine and the splice connector of the present invention used within a channel lettering system.

FIGURE 8 illustrates an exploded perspective view of a suitable embodiment of a channel lettering system incorporating an intermediate stencil.

FIGURE 9 illustrates a perspective view of a portion of the LED light engine of FIGURE 8 and its mounting to a portion of the stencil.

FIGURE 10 illustrates an enlarged perspective view of one LED device of FIGURE 9 including a snap-on connector.

FIGURE **11** illustrates an exploded perspective view of the LED device of FIGURE **10**.

FIGURE **12** illustrates the insulation-piercing members of the connector of FIGURES **10** and **11**, and their interconnection with the LED leads inside the connector (connector body not shown in FIGURE **12**).

FIGURE **13** illustrates the connecting of the insulation-piercing members with the conductors of the flexible electrical cable.

FIGURE **14** illustrates an exploded view of the snap-on splice connector of FIGURE **9**.

FIGURE **15** illustrates a perspective view of an uncut stencil which is suitable for forming the shaped stencil of FIGURE **8**.

FIGURE **16** illustrates a channel lettering with a suitable arrangement of independently adjustable power supply outputs.

DETAILED DESCRIPTION OF THE INVENTION

With reference to FIGURE **1**, a light emitting diode (LED) light engine **10** includes a flexible electrical conductor **12** surrounded by a flexible, electrically insulating covering **14**. More specifically, the conductor **12** includes a plurality of substantially parallel conductive elements **16**, each of which is electrically insulated by the insulating covering **14**. In the preferred embodiment, the insulating covering **14** includes rubber, PVC, silicone, and/or EPDM. However, other material are also contemplated.

Preferably, the conductor **12** includes two conductive elements **16a, 16b**. Furthermore, each of the conductive elements **16a, 16b** is preferably sized to be about 14 gauge. Additionally, each of the conductive elements **16a, 16b** is preferably stranded and includes a plurality of strands **18** (e.g., seven strands).

The LED light engine **10** also includes an LED **20**, which electrically contacts the conductive elements **16** and is mechanically secured to the insulating covering **14**. More specifically, with reference to FIGURE 2, the LED **20** includes a plurality of electrical leads **22** (e.g., one pair or two pairs of the leads **22**).

Although only one pair of the leads **22a, 22b** is necessary, additional pairs of the leads **22c, 22d** offer added stability to the LED **20** mounted on the conductor. Also, additional pairs of the leads **22** provide means for dissipating heat, thereby permitting more current to be used for powering the LED **20**. Each of the pairs of leads **22** includes a first lead **22a, 22d**, which connects, for example, to a negative electrical power source and a second lead **22b, 22c**, which connects, for example, to a positive electrical power source. The LED **20** typically a two-terminal device having an anode and a cathode. In a suitable embodiment, the first lead **22a, 22d** corresponds to the anode of the LED **20** and directly electrically connects to the conductive element **16a**, and the second lead **22b, 22c** corresponds to the cathode of the LED **20** and directly electrically connects to conductive element **16b**.

With reference to FIGURES **1** and **2**, the LED **20** is mechanically and electrically secured to the conductor **12** by passing the leads **22** through the insulating covering **14** via an insulation displacement technique. Furthermore, after passing through the insulating covering **14**, the leads **22** contact the respective conductive elements **16**. Preferably, the leads **22** include tips that are wedge-shaped needles. The wedge-shaped needle tips of the leads **22** pass between the strands **18** of the respective conductive elements **16a, 16b** to form electrical contacts between the leads **22** and the conductive elements **16**.

Preferably, the LED **20** is secured to the conductor **12** when the conductor **12** is positioned flat (i.e., when the conductive elements **16a, 16b** run in a common substantially horizontal plane which is above a horizontal surface).

Optionally, the conductor **12** includes two dips (grooves) **24a, 24b** in the insulating covering **14**. The dips **24a, 24b** are positioned substantially above the respective conductive elements **16a, 16b**, respectively. Before the LED **20** is secured to the conductor **12**, the leads **22** are placed in the dips **24a, 24b** and, therefore, aligned over the conductive elements **16a, 16b**, respectively. Then, after being aligned in the dips **24**, the leads **22** are passed through the insulating covering **14** and inserted into the conductive elements **16**.

With reference to FIGURES 3 and 4, an alternate embodiment which includes a light engine **40** that secures an LED **50** to a conductor **52** via a connector **54** is illustrated. The connector **54** includes first and second sections **54a, 54b**. The LED **50** is secured within the first section **54a** before both of the sections **54a, 54b** are secured (e.g., snapped or clamped) together. As in the first embodiment, the conductor **52** is flexible and includes a plurality of conductive elements **56a, 56b** (e.g., two conductive elements) and an insulative covering electrically isolating each of the conductive elements **56a, 56b**. Furthermore, the conductive elements **56a, 56b** are optionally stranded and include, for example, seven strands **58**.

Optionally, a hole **60** is formed in one of the sections **54b** through which a means for securing (e.g., a fastener such as a screw, nail, bolt, etc.) is inserted for securing the connector **54** to a wall or other support means. For example, the connector **54** may be secured to a wall of a channel lettering housing (see FIGURE 7).

The connector section **54b** includes a plurality of electrical contacts **62** that, once the sections **54a, 54b** are snapped together, electrically contact the LED **50**. As is discussed below, the contacts **62**, along with the sections **54a, 54b**, are used for mechanically securing the connector **54** to the conductor **52**. A plurality of pairs of the contacts **62** electrically communicate with each other. More specifically, the contacts **62a, 62c** electrically communicate with each other while the contacts **62b, 62d** electrically communicate with each other. In a suitable embodiment, the electrical communication is a direct electrical contacting, i.e. the contacts **62a, 62c** are electrically continuous and the contacts **62b, 62d** are electrically continuous.

One set of the contacts **62a, 62c**, for example, is electrically connected to a positive source of electrical power while the other set of the contacts **62b, 62d**, for example, is electrically connected to a negative source of the electrical power. In this manner, the anode of the LED **50** is in direct electrical contact with the positive source while the cathode of the LED **50** is in direct electrical contact with the negative source of electrical power. The set of contacts

62a, 62c is electrically isolated from the set of contacts **62b, 62d**. Furthermore, the electrical contacts **62** are V-shaped and sized to accept conductive elements **56a, 56b** within the respective V-shaped spaces. More specifically, the tips of the V-shaped electrical contacts **62** are sharp and formed for displacing (piercing) the insulative coverings around the conductive elements **56a, 56b**.

Although only two of the contacts **62a, 62b** (or, alternatively, **62c, 62d**) is necessary, the connector **54** preferably includes two pairs of the contacts **62** to offer added stability to the mechanical connection between the connector **54** and the conductor **52**.

After displacing the insulative coverings, the conductive elements **56a, 56b** are passed into the V-shaped spaces of the electrical contacts **62**. As the conductive elements **56a, 56b** are passed into the V-shaped spaces, the strands within the conductive elements **56** are wedged into the vertex of the "V." In this manner, a secure electrical contact is made between the conductive elements **56** and the respective electrical contacts **62**. Furthermore, the strands are squeezed such that a shape of the conductor changes, for example, from round to oval. Also, as the strands are squeezed, spaces between the strands is reduced such that an overall size (e.g., diameter or circumference) of the respective conductive element **56a, 56b** is reduced, for example, to a size of an "un-squeezed" three strand connector.

Preferably, the connector **54** is secured to the conductor **52** when the conductor **52** is positioned on-edge (i.e., when the conductive elements **56a, 56b** run in substantially parallel horizontal planes above a substantially horizontal surface).

It is to be understood that although the embodiments have been described with reference to a single LED **20** (FIGURE **1**) and a single LED connector **54** (FIGURE **3**) on the conductors **12, 52**, respectively, a plurality of LEDs **20** (FIGURE **1**) and LED connectors **54** (FIGURE **3**) on the conductors **12, 52**, respectively, are contemplated so that the light engines **10, 40** form respective LED strips. Furthermore, the LEDs **20** (FIGURE **1**) and LED connectors **54** (FIGURE **3**) on the conductors **12, 52** of the respective LED light strips **10, 40** are

preferably spaced about two inches apart from each other. However, other spacings between the LEDs **20** and the LED connectors **54** are also contemplated.

Furthermore, if a plurality of the LEDs **20** are secured to the conductor **12** (FIGURE **1**), which is oriented in a flat position, the conductor **12** is flexible in a first direction. However, if a plurality of the connectors **54** are secured to the conductor **52** (FIGURE 3), which is oriented in an on-edge position, the conductor **52** is flexible in a second direction.

With reference to FIGURES **5** and **6**, a splice connector **70** mechanically and electrically connects a plurality of flexible conductors (e.g., two conductors) **72, 74** together. Like the connector **54** (see FIGURE 3), the splice connector **70** includes a plurality of portions (e.g., two portions) **70a, 70b.** Preferably, the portions **70a, 70b** are slidably interconnected to each other. Furthermore, the portions **70a, 70b** slide between two positions (e.g., an open position and a closed position). In the closed position, the portions **70a, 70b** are secured together via locking tabs **71**, which engage mating tabs **73**. Although only one locking tab **71** and one mating tab **73** is shown in FIGURE **6**, it is to be understood that additional locking and mating tabs are also contemplated. Furthermore, like the conductor **52** and the connector **54** of FIGURE **3**, the splice connector **70** of FIGURES **5** and **6** is preferably secured to the conductors **72** (shown), **74** (not shown) when the conductors **72, 74** are oriented in an on-edge position. Also, the splice connector **70** includes a plurality of electrical contacts **76** (e.g., two electrical contacts), which are preferably V-shaped and function in a similar manner to the contacts **62** shown in FIGURE **4**. In the closed position, the locking tabs **71** are secured by the mating tabs **73** such that the conductors **72, 74** are secured within the V-shaped contacts **76**.

The conductors **72, 74** are aligned parallel and on-edge with respect to one another. Then, the splice connector **70** is secured around both of the conductors **72, 74**. In this manner, respective first conductive elements **72a, 74a** are mechanically and electrically secured to one another; similarly, respective

second conductive elements **72b**, **74b** are mechanically and electrically secured to one another.

With respect to FIGURE **7**, a channel lettering system **80** includes LEDs **82** mechanically and electrically connected to flexible conductors **84** according to the present invention. It is to be understood that the LEDs **82** are either directly connected to the conductors **84** (as shown in FIGURE **1**) or connected to the conductors **84** via connectors **54** (as shown in FIGURE **3**). Furthermore, the splice connector **70** is shown mechanically and electrically connecting the conductor **84** to an additional conductor **86**.

With reference to FIGURES **8-16**, yet another suitable embodiment of an illuminated sign or channel lettering **88** is described. As shown in FIGURE **8**, a flexible light engine **90** is mounted on a stencil **92** which defines a selected shape, e.g. the capital letter "E", which conforms with a housing **94** also conforming to the letter "E" and including at least a translucent surface **96** arranged to pass light generated by the curvilinear LED light source **90**. The stencil **92** is shaped for arrangement in the housing **94**.

With continuing reference to FIGURE **8** and with further reference to FIGURE **9**, the flexible light engine **90** includes an insulated flexible electrical cord **100** on which a plurality of LED devices **102** are disposed in a spaced apart manner. Each LED device **102** includes an LED **104** with a lead frame which is affixed in a first region **106** of a connector **108**. The connector **108** also includes a second region **110** that clamps onto the cord **100**. The second region **110** includes a snap-type connector similar to that previously described with reference to FIGURES **3** and **4**, and similarly serves to connect the LED **104** with parallel electrical conductors **112**, **114** of the cord **100**. As shown in FIGURE **9**, the conductors **112**, **114** are maintained at an essentially constant separation by an insulating sheath **115** of the cord **100**, and so the clamping connectors **108** can be placed anywhere along the cord **100**.

Because the LED devices **102** are spaced apart along the flexible electrical cable **100**, for example at two-inch spacings, the intervening cable portions between the LED devices **102** can bend to define a channel letter shape

or other selected pattern, such as the letter "E" formed by the light engine **90** in FIGURE **8**. In the embodiment of FIGURES **8-16**, it will be appreciated that the two parallel electrical conductors **112, 114** within the insulating sheath **115** of the cord **100** define a spatially localized cable plane containing the two conductors **112, 114**. The cable **100** is bendable in a direction out of the local cable plane, whose orientation varies with the bending of the cable **100**, but is relatively inflexible in the local cable plane, since bending within the local cable plane produces compressive and tensile forces along the axes of the conductors **112, 114**. Hence, the cable **100** is bendable in the plane of the stencil **92** to form the light engine **90** into a pattern on the stencil **92**. Note that the plane of the stencil **92** is everywhere perpendicular to the local cable plane as the cable is bent to conform with a selected lettering. It will also be recognized that the LED devices **102** are oriented such that illumination produced by the LEDs **104** is substantially directed parallel to the local cable plane, i.e. perpendicular to the plane of the stencil **92**, so that the LED devices **102** produce illumination directed away from the stencil **92**.

The second region **110** advantageously employs a mechanical connection which also effectuates the electrical connections of the LED **104** to the conductors **112, 114** in a manner similar to that described previously, e.g. using electrical leads **62** (see FIGURES **3** and **4**) that penetrate the electrical insulation **115** of the cord **100** during the mechanical snap connection. Optionally, the second region **110** supports detachable attachment, such as an un-snapping removal of the connector **108** from the cord **100**. Although such detachment can leave small openings where the insulation **115** has been displaced, the potential difference applied across the LED devices **102** in the parallel interconnection is typically low, such as a few volts corresponding to typical optimal forward voltages for commercial LEDs, and so significant safety hazards are not presented by the degraded insulation.

With continuing reference to FIGURES **9** and **10**, each connector **108** additionally includes a third region **116** adapted to cooperate with a fastener **118** for securing the connector **108** to the stencil **92**. In the illustrated

embodiment, the third region **116** includes a slot **120** that receives the fastener **118**, which in the illustrated embodiment is an exemplary threaded screw. The fastener **118** shaft passes through the slot **120** and threads into one of a plurality of openings **122** arranged in the stencil **92**.

With particular reference to FIGURE **9**, the cable **100** includes two lengths of cable **100_1**, **100_2** that are spliced together using a snap-on splice connector **124**, which is described later in greater detail with reference to FIGURE 14. The splice connector electrically connects the conductors **112** of the two cables **100_1**, **100_2** to form one continuous conductor, and also electrically connects the conductors **114** of the two cables **100_1**, **100_2** to form another continuous conductor. The combined conductors **112**, **114** are electrically isolated from one another by the insulating coating or sheath **115**. Additionally, FIGURE **9** shows a power connector **126** which connects with the cord **100** using the same type of snap-on clamp as is employed by the second region **110** of the connector **108**. The exemplary power connector **126** includes receptacles **128** adapted to connect with prongs of a power cable connector (not shown). Although the power connector **126** is shown connected near an end of the curvilinear LED light source **90**, it will be appreciated that due to the parallel electrical configuration of the source **90** the power connector **126** can instead be arranged essentially anywhere along the source **90**, including between LED devices **102**. Indeed, the choice of where to clamp the power connector **122** onto the curvilinear LED light source **90** is preferably determined by the geometry of the illuminated sign **88** and by the location of the driving power source (see FIGURE **16**). Optionally, the power connector can be integrated into a splice connector or into an LED connector.

With particular reference to FIGURES **11** and **12**, assembly of an exemplary LED device **102** is described. The LED **104** includes leads **130**, specifically two positive leads **130_P** electrically communicating with the positive terminal or anode of the LED **104**, and two negative leads **130_N** (one of which is blocked from view in FIGURES **11** and **12**) electrically communicating with the negative terminal or cathode of the LED **104**. The LED **104** also preferably includes a light-transmissive encapsulant **132** encapsulating a semiconductor chip

or other electroluminescent element (not shown). The encapsulant **132** is optionally formed into a lens or other selected light-refractive shape. Furthermore, the encapsulant **132** optionally includes a phosphorescent material, a tinting, or the like that changes or adjusts the spectral output of the LED **104**. Those skilled in the art will recognize that the LED **104** is substantially similar to commercially available LED packages, such as the P4 (piranha) LED package.

The first region **106** includes a socket that receives the LED **104** with the light-emitting surface (i.e., the surface with the encapsulant **132** disposed thereon) facing away from the connector **108** and the LED leads **130** inserting into the socket. The connector **108** includes a first section **140** with the first region **106** that provides the LED mount or socket, and a second section **142** that connects with the first section **140** in a clamping or snapping fashion. The second region **110** including the clamp, mechanical snap connection, or the like is defined by the connection of the two sections **140**, **142** about a portion of the flexible electrical cable **100**.

With continuing reference to FIGURES **11** and **12**, the first section **140** also includes positive and negative conductive insulation-piercing members or prongs $\mathbf{144}_P$, $\mathbf{144}_N$ that are arranged in a substantially fixed manner in slots or openings (not shown) of the first section **140** of the connector **108**. Each prong **144** is substantially planar and includes slots **146** that compressively receive the corresponding (positive or negative) LED leads **130** to effectuate electrical contact of the positive and negative terminals (anode and cathode) of the LED with the corresponding positive or negative prong $\mathbf{144}_P$, $\mathbf{144}_N$. The receiving of the LED leads **130** into the slots **146** is compressive and does not include a soldering step. Hence, it is contemplated that the LED **104** is optionally detachable from the socket region **106** of the first section **140**, for example to facilitate replacement of a failed LED **104**.

Assembly of the first section **140** of the connector **108** includes inserting the prongs $\mathbf{144}_P$, $\mathbf{144}_N$ into the first section **140**, and inserting the LED **104** into the socket of the first region **106** so that the LED leads **130** compressively fit into the slots **146** of the prongs **144** to effectuate electrical

contact therewith. In a preferred embodiment, the first section **140** is a molded body of plastic or another electrically insulating material, the prongs **144** are formed from sheet metal or another substantially planar electrically conductive material, and the LED **104** is a pre-packaged LED of a type known to the art, e.g. an electroluminescent semiconducting element arranged in a P4 (piranha) package with suitable epoxy or other encapsulant. It will be appreciated that a significant advantage of the connectorized LED device **102** is that assembly thereof involves no soldering steps.

With continuing reference to FIGURES **11** and **12**, and with further reference to FIGURE **13**, each prong **144** includes a "V"-shaped or bifurcated end **148** that extends out of the first section **140** toward the second section **142** such that when the first and second sections **140, 142** are clamped or snapped together with the cable **100** arranged therebetween the ends **148** of the prongs **144** puncture the cable insulation **115** and contact the conductors **112, 114**. Each bifurcated end **148** defines a gap **150** sized to receive the respective conductor **112, 114** of the flexible electrical cable **100**. As best seen in FIGURE **13**, each conductor **112, 114** is a multi-stranded conductor which compressively squeezes into the gap **150** of one of the prongs 144_P, 144_N when the two connector sections **140, 142** are clamped or snapped about the cable **100**. The compression preferably does not break or fracture the individual strands of the conductors **112, 114**, but does ensure a reliable electrical contact between the prongs 144_P, 144_N and the respective conductors **112, 114.**

It will be appreciated that the snapping connection of the first and second sections **140, 142** about the cable **100** effectuates both a mechanical connection of the LED device **102** to the cable **100** as well as a simultaneous electrical connection of the positive and negative (anode and cathode) terminals of the LED **104** via the prongs 144_P, 144_N to the conductors **112, 114** that supply electrical power. The electrical connection does not include auxiliary electrical components, such as resistors or the like, and does not include soldering. Hence the LED device **102** includes few component parts in the channel lettering which reduces the likelihood of device failure. However, it is also contemplated to

include resistive or other circuit elements in the connector **108** to perform selected power conditioning or other electrical operations.

Preferably, the conductors **112, 114**, the prongs **144_P, 144_N**, and the LED leads **130** are formed from substantially similar metals to reduce galvanic corrosion at the electrically contacting interfaces, or are coated with a conductive coating that reduces galvanic corrosion at the interfaces. In a suitable embodiment, the conductors **112, 114**, the prongs **144_P, 144_N**, and the LED leads **130** are each coated with a conductive coating of the same type, which ensures that galvanic corrosion at the contacting surfaces is minimized. Particularly in the case of high power LED devices **102**, embodiments that employed contacting surfaces with mismatched compositions typically experienced significant detrimental galvanic corrosion at the contacting surfaces.

With reference to FIGURES **10** and **11**, the first connector section **140** includes a clip **154** that cooperates with a recess or receiving region **156** of the second connector section **142** to snappingly secure the first and second sections **140, 142** together onto the cable **100**, as shown in the secured position in FIGURE **10**. Of course, other securing mechanisms can also be employed.

With reference to FIGURE **9** and with further reference to FIGURE **14**, the splice connector **124** employs a similar simultaneous electrical/mechanical connection of the splice connector **124** to cables **100_1, 100_2** to splice the cables **100_1, 100_2** together. The splice connector **124** includes three sections **160, 162, 164**, which are preferably formed of a molded plastic or other insulating material. The section **162** is a middle section that includes positive and negative double-ended insulation-piercing elements or prongs **166_P, 166_N** that insert into slots **168_P, 168_N** of the section **162** in a substantially rigid manner similar to the inserting of the prongs **144_P, 144_N** into the section **140** of the connector **108** of the LED devices **102**. The prongs **166_P, 166_N** preferably include bifurcated ends **150** as with the prongs **144_P, 144_N** of the LED devices **102**, which are sized to squeeze the multi-stranded conductors **112, 114** without fracturing conductor strands.

With continuing reference to FIGURES **9** and **14**, the sections **160**, **162** of the splice connector **124** mechanically snap onto the flexible electrical cable $\mathbf{100_2}$. The snapping together causes the prong ends $\mathbf{150_1}$, $\mathbf{150_2}$ to pierce the insulation **115** and connect with the conductors **112**, **114**, respectively, of the cable $\mathbf{100_2}$. The snapping connection includes engagement of a clip **170** of the connector section **162** with a recess **172** of the connector section **160** to secure the sections **160**, **162** about the cable $\mathbf{100_2}$. Similarly, the sections **162**, **164** of the splice connector **124** mechanically snap onto the flexible electrical cable $\mathbf{100_1}$ with prong ends $\mathbf{150_3}$, $\mathbf{150_4}$ piercing the insulation **115** and connecting with the conductors **112**, **114**, respectively, of the cable $\mathbf{100_1}$. The snapping connection includes engagement of a clip **174** of the connector section **162** with a recess **176** of the connector section **164** to secure the sections **162**, **164** about the cable $\mathbf{100_1}$. Hence, the prong $\mathbf{166_P}$ provides electrical connection between the conductors **112** of the cables $\mathbf{100_1}$, $\mathbf{100_2}$, while the prong $\mathbf{166_N}$ provides electrical connection between the conductors **114** of the cables $\mathbf{100_1}$, $\mathbf{100_2}$, to electrically connect the cables during the mechanical connecting of the cables $\mathbf{100_1}$, $\mathbf{100_2}$ by the splice connector **124**.

With reference to FIGURES **8** and **9** and with further reference to FIGURE **15**, construction of the exemplary illuminated sign **88** is advantageously modular and selectably divided between the manufacturer and the end user. In one suitable embodiment, the LEDs **104** are installed on the connectors **108** to form the LED devices **102**, and the LED devices **102** are snapped onto the flexible cable **100** at the factory to form the manufactured flexible light engine **90**. A stencil board **180** shown in FIGURE **15** includes pre-formed openings **122**, and can be cut at the installation site to match the selected letter housing **94**, e.g. the stencil board **130** is cut to form the exemplary "E"-shaped stencil **92**. Suitable lengths of the flexible LED light source **90** are cut off and affixed on the shaped stencil **92** using the third regions **116** of the connectors **108** and fasteners **118** applied to selected pre-formed openings **122**. Splices **124** are applied as appropriate, and the power connector **126** is snapped onto the cord **100** at a selected convenient point. Optionally, the pre-formed openings **122** are omitted,

and the fasteners **118** displace the stencil material to fasten thereto. For example, the displacing fasteners can be wood screws with sharp tips for engaging and penetrating the stencil material.

In a variation of the above installation process, the LEDs **104** are installed on the connectors **108** at the factory, but the LED devices **102** are snapped onto the cable **100** at selected locations along the cable **100** at the installation site. This approach is more labor-intensive at the installation site, but provides maximum flexibility in the selection and spacing of the LED devices **102** along the cord **100**. Such a modular system can allow the end-user to select the colors of the LEDs **104** to create a custom multi-color flexible LED light source **90**.

In yet another variation, the connector **108** is optionally omitted similarly to the previously-described embodiment of FIGURES **1** and **2**, and the LED leads $\mathbf{130_P}$, $\mathbf{130_N}$ directly affixed to the cord **100**. Any of the above installation/assembly processes are particularly suitable for retro-fitting an existing channel lettering. The shaped stencil **92** advantageously allows the light source **90** to be routed around or over obstructions or features such as cross-members within the existing channel letter.

With continuing reference to FIGURES **8-15**, and with further reference to FIGURE **16**, a channel lettering **200** that displays "TEXT" is shown. The channel lettering portion "TE" is powered by a first power supply **210** which includes two power output lines **212, 214**. The channel lettering portion "XT" is powered by a second power supply **220** which includes two power output lines **222, 224**.

Each power supply **210, 220** is arranged away from the illuminated channel lettering "TEXT", for example in the interior of an associated building, and includes conditioning electronics for converting building power (e.g., 120V a.c. in the United States, or 220V a.c. in Europe) to power suitable for driving the LED light sources of the channel lettering. Since a parallel electrical connection is used in the light engine **90**, the output power is low voltage, corresponding to the driving voltage of a single LED, and so a low voltage power supply can be employed. In a preferred embodiment, the power supplies **210, 220** are class II

power supplies which have output power limited to 5 amperes and 30 volts. Class II power supplies are relatively safe due to the low voltages and currents produced thereby, and the output lines **212**, **214**, **222**, **224** are typically not required by electrical codes to be arranged in safety conduits.

Of course, each power supply can include a different number of power output lines, e.g. one, three, or more power output lines. Each power output line provides a selectable electrical output power, for example as monitored by the meters **226**. In a preferred embodiment, the power delivered to each power output line is individually controllable using a knob **228** or other control input. This permits balancing the light intensity of the letters, e.g. of the letters "T", "E", "X", and "T", to obtain a uniformly lit sign "TEXT".

FIGURE 16 also schematically shows the use of a splice connector **230**, such as the splice connector **124** of FIGURE **14**, to connect the upper and lower cable lengths **232**, **234** of the "X" channel letter. Note that this splicing is arranged in the middle of each of the two flexible electrical cable lengths **232**, **234**. It will be appreciated that the splice connector can be connected substantially anywhere along the length of an electrical cable to provide great flexibility in cable arrangement.

The invention has been described with reference to the preferred embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

WHAT IS CLAIMED IS:

1. An illuminated sign comprising:

a flexible electrical power cord including first and second parallel conductors surroundingly contained within an insulating sheath defining a constant separation distance between the parallel conductors;

a plurality of light emitting diode (LED) devices affixed to the cord, each LED device including an LED having a positive lead electrically communicating with the first parallel conductor and a negative lead electrically communicating with the second parallel conductor;

a stencil defining a selected shape and onto which the electrical cord is arranged; and

power conditioning electronics disposed away from the stencil and electrically communicating with the first and second parallel conductors of the electrical power cord, the power conditioning electronics powering the LED devices via the parallel conductors.

2. The illuminated sign as set forth in claim 1, further including:

a housing inside which the stencil, LED devices, and electrical power cord are arranged, the power conditioning electronics disposed outside of and away from the housing, the housing further defining the selected shape and including a light transmissive region arranged to transmit light generated by the plurality of LED devices.

3. The illuminated sign as set forth in claim 1, wherein each LED device includes:

a connector including:

a first region onto which an LED is secured, and

a second region that mechanically connects with the electrical power cord, the second region including a positive prong that electrically contacts the positive LED lead and the first parallel

conductor, and a negative prong that electrically contacts the negative LED lead and the second parallel conductor.

4. The illuminated sign as set forth in claim 3, wherein each connector further includes:

a flange adapted for affixing the connector to the stencil.

5. The illuminated sign as set forth in claim 3, wherein the second region includes a fastener that mechanically secures onto the electrical power cord, the mechanical securing simultaneously electrically contacting the positive and negative prongs with the first and second conductors, respectively.

6. The illuminated sign as set forth in claim 1, wherein the flexible electrical power cord further includes:

a plurality of cords each including first and second parallel conductors surroundingly contained within a continuous insulating sheath defining a constant separation distance between the parallel conductors; and

at least one splice connector that mechanically joins the plurality of cords, the splice connector electrically connecting the first conductors of the plurality of cords, and electrically connecting the second conductors of the plurality of cords.

7. An article of manufacture for installing a plurality of light emitting diodes (LEDs) into a channel letter housing having at least one light-transmissive surface, the article of manufacture comprising:

a substantially rigid structure which is pre-formed or formable for arrangement in the channel letter housing;

a flexible cable including at least two flexible parallel conductors arranged to support an electrical potential difference therebetween;

a plurality of LEDs electrically parallel-interconnected by communication of the anode and cathode of each LED with the at least two conductors of the flexible cable;

a fastener that secures at least a portion of the flexible cable onto the rigid structure; and

a power module that receives power having first characteristics and converts the received power to a supply power having second characteristics which is communicated to the at least two conductors of the flexible cable to power the plurality of parallel-interconnected LEDs.

8. The article of manufacture as set forth in claim **7**, further including:

a plurality of connectors corresponding to the plurality of LEDs, each connector retaining an LED and mechanically connecting with the cable, and each connector including a first conductive element that contacts the LED anode and one of the at least two conductors, each connector further including a second conductive element that contacts the LED cathode and another of the at least two conductors.

9. The article of manufacture as set forth in claim **8**, wherein the fastener for securing at least a portion of the flexible cable onto the rigid structure includes:

a bracket arranged on each of the plurality of connectors for securing the connector to the rigid structure.

10. The article of manufacture as set forth in claim **8**, wherein the connector further includes:

first and second connector sections that snap together about a portion of the flexible cable to secure the connector to the cable portion.

11. The article of manufacture as set forth in claim **10**, wherein the connecting region includes:

ends of the first and second conductive elements that extend outward from the first connector section toward the second connector section, the ends

including insulation-piercing tips that displace an insulative coating of the flexible cable to contact the respective two cable conductors.

12. The article of manufacture as set forth in claim **11**, wherein the insulation-piercing tips each include:

a bifurcated portion that receives the respective cable conductor.

13. A light emitting diode (LED) light engine, comprising:

an electrical cable including:

at least two flexible electrical conductors, and

a flexible, electrically insulating covering surrounding the electrical conductors, the conductors arranged substantially parallel with a selected separation therebetween; and

an LED with a plurality of electrical leads separated by the selected separation which electrically contact the electrical conductors and mechanically pierce the insulating covering to mechanically secure the LED to the electrical cable.

14. The LED light engine as set forth in claim **13**, wherein each of the conductors includes a plurality of strands and is about 14 gauge.

15. The LED light engine as set forth in claim **13**, wherein each of the electrical leads is wedge-shaped.

16. The LED light engine as set forth in claim **13**, wherein the flexible covering includes a plurality of dips positioned for aligning the leads with the flexible elements.

17. A light emitting diode (LED) light engine including:

an electrical cable including a positive flexible conductor connected with an associated positive source of electrical power, a negative flexible conductor connected with an associated negative source of electrical power, and an

electrically insulating covering surrounding and electrically insulating the positive and negative conductors and holding the conductors separate at a selected separation distance;

an LED including positive and negative leads; and

a connector mechanically secured to the flexible insulating covering, the connector including positive and negative prongs that pierce the insulating covering and electrically contact the positive and negative conductors, respectively, the connector further having the LED mounted thereon with the positive and negative leads of the LED electrically contacting the positive and negative prongs, respectively.

18. The LED light engine as set forth in claim **17**, wherein:

each of the connector prongs is V-shaped; and

each of the electrical cable conductors is positioned within an opening defined by the respective V-shaped connector prong.

19. The LED light engine as set forth in claim **18**, wherein the connector includes a locking tab for securing the connector in a locked position, the cable conductors being positioned within the respective V-shaped connector prongs when the connector is in the locked position.

20. A method of manufacturing an LED light engine, the method comprising:

insulating a plurality of conductive elements to form a flexible electrically insulating conductor;

mechanically securing an LED to the insulated conductive elements; and

simultaneously with the mechanical securing, electrically contacting a plurality of leads of the LED to respective ones of the conductive elements.

21. The method of manufacturing an LED light engine as set forth in claim **20**, wherein the securing step includes:

displacing an insulating covering over one of the conductive elements; and inserting one of the LED leads into the displaced covering.

22. The method of manufacturing an LED light engine as set forth in claim **21**, wherein the conductive elements include a plurality of conductive strands, the contacting step including:

passing one of the LED leads through an insulating covering over one of the conductive elements; and

inserting the LED lead between the conductive strands of the conductive element.

23. The method of manufacturing an LED light engine as set forth in claim **22**, wherein the insulating covering includes a groove, further including, before the passing step:

aligning the LED lead with the conductive element via the groove.

24. The method of manufacturing an LED light engine as set forth in claim **20**, wherein:

the securing step includes:

mechanically attaching a connector to an insulating covering on the conductor; and

the contacting step includes:

passing an electrical contact, secured to the connector, through the insulating covering so that an electrical connection is made between the contact and a respective one of the conductive elements.

25. The method of manufacturing an LED light engine as set forth in claim **24**, wherein the electrical contact is V-shaped, the passing step including:

securing the conductive element within the V-shaped contact.

26. A flexible lighting device comprising:

a flexible cable including an electrically insulating sheath which contains positive and negative conductors electrically isolated from one another, the sheath providing a spacing between the positive and negative conductors; and

a plurality of light emitting diode (LED) devices spaced apart from one another on the cable, each of the LED devices having an LED including positive and negative leads mounted on a connector which mechanically secures the LED device to a portion of the flexible cable and electrically connects the positive and negative LED leads to the positive and negative conductors through positive and negative conductive piercing members which pierce the sheath to make electrical contact with the respective conductors.

27. The flexible lighting device as set forth in claim **26**, wherein each connector includes:

an LED mount region that receives the LED;

a clamp region that secures the connector to the portion of the flexible cable, the clamp region aligning the positive and negative conductive piercing members with the positive and negative conductors of the flexible cable, each conductive piercing member including an insulation-piercing end that displaces the insulating sheath when the clamp region is secured to electrically contact with the respective conductor; and

a fastening region for fastening the connector onto an associated supporting structure.

28. The flexible lighting device as set forth in claim **27**, wherein the fastening region of each connector includes:

an opening adapted to cooperate with a fastener to fasten the connector to the associated supporting structure.

29. The flexible lighting device as set forth in claim **26**, wherein each conductive piercing member includes:

a bifurcated end defining a gap sized to receive the respective conductor.

30. The flexible lighting device as set forth in claim **29**, wherein each electrical cable conductor is a multi-stranded conductor, and the conductor is compressively held within the bifurcated end.

31. The flexible lighting device as set forth in claim **26**, wherein each connector includes:

a first section including an LED mount region that receives the LED; and

a second section that cooperates with the first section to define a clamp region;

wherein the first and second sections snap together with the flexible cable portion arranged therebetween to secure the connector to the flexible cable, the snapping causing the conductive piercing members to pierce the sheath and make electrical contact with the respective conductors.

32. The flexible lighting device as set forth in claim **31**, wherein the insulating sheath of the flexible cable includes:

dips arranged on the surface of the sheath and corresponding with the positive and negative electrical conductors, the dips receiving ends of the conductive piercing members to align the flexible cable portion between the first and second connector sections prior to the snapping theretogether.

33. The flexible lighting device as set forth in claim **26**, wherein the positive and negative conductors within the insulating sheath define a cable plane, the flexible electrical cable being flexible in a direction out of the cable plane, the LED emitting light substantially directed parallel to the cable plane.

34. The flexible lighting device as set forth in claim **26**, wherein intervening cable portions between the spaced apart LED devices are selectively flexed to define a selected channel lettering.

35. The flexible lighting device as set forth in claim **26**, wherein the flexible cable includes first and second flexible cables, the flexible lighting device further including:

a splice connector that mechanically and electrically connects first and second flexible cables, the splice connector including positive and negative conductive piercing members which pierce the sheaths of the first and second cables to make electrical contact with the respective conductors.

36. A light emitting diode (LED) lighting apparatus comprising:

a flexible electrical cable including an anode wire and a cathode wire arranged in an electrically isolating sheath;

a plurality of LED devices spaced apart along the cable and mechanically and electrically connected therewith, each LED device including:

an LED having at least one anode lead and at least one cathode lead, and

a connector including an LED socket that receives the anode and cathode leads, the LED socket mechanically retaining the LED, the connector further including a first electrically conductive path between the anode lead and the anode wire, and a second electrically conductive path between the cathode lead and the cathode wire, the first and second conductive paths displacing portions of the cable sheath.

37. The LED lighting apparatus as set forth in claim **36**, wherein the first and second conductive paths each include:

an electrically conductive element contacting the LED lead, the conductive element including an insulation-piercing end that displaces a portion of the cable sheath and contacts the respective cable wire.

38. The LED lighting apparatus as set forth in claim **37**, wherein the connector includes first and second sections that surroundingly clamp onto a

portion of the cable, the insulation piercing ends of the first and second conductive paths extending into the clamp portion such that they pierce the cable sheath responsive to the clamping to effectuate contact with the respective cable wires.

39. The LED lighting apparatus as set forth in claim **37**, wherein each insulation piercing end includes a bifurcation that receives a portion of the anode or cathode wire without cutting said wire.

40. The LED lighting apparatus as set forth in claim **37**, wherein the LED leads and the conductive elements include an electrically conductive surface material of the same type.

41. The LED lighting apparatus as set forth in claim **37**, wherein the anode and cathode wires and the conductive elements include an electrically conductive surface material of the same type.

42. The LED lighting apparatus as set forth in claim **37**, wherein the anode and cathode wires, the conductive elements, and the LED leads each include an electrically conductive surface selected to substantially reduce galvanic corrosion at electrically contacting surfaces therebetween.

43. The LED lighting apparatus as set forth in claim **37**, wherein the contacting of the electrically conductive element with the LED lead effectuates electrical contact without cooperation of an electrically conductive solder.

44. The LED lighting apparatus as set forth in claim **36**, wherein the first and second conductive paths include:

an electrically conductive anode prong;

an electrically conductive cathode prong;

an anode prong recess that receives the anode prong; and

a cathode prong recess that receives the cathode prong;

wherein the prong recesses communicate with the LED socket such that the LED leads penetrate the prong recesses to contact with the prongs.

45. The LED lighting apparatus as set forth in claim 36, wherein each connector includes one LED socket.

46. The LED lighting apparatus as set forth in claim 36, further including:

a stencil defining a selected letter or symbol, the flexible electrical cable arranged on the stencil to light the selected letter or symbol.

47. The LED lighting apparatus as set forth in claim 46, wherein the electrical cable is fastened onto the stencil via the connectors.

48. The LED lighting apparatus as set forth in claim 46, wherein the stencil includes a plurality of stencils defining a plurality of letters or symbols, and the flexible electrical cable includes a plurality of flexible electrical cables arranged on the plurality of stencils, the LED lighting apparatus further including:

a power supply having a plurality of individually adjustable power output lines each electrically powering one or more flexible electrical cables, the individually adjustable power output lines selectively adjusted such that the intensities produced by the flexible electrical cables are substantially uniform.

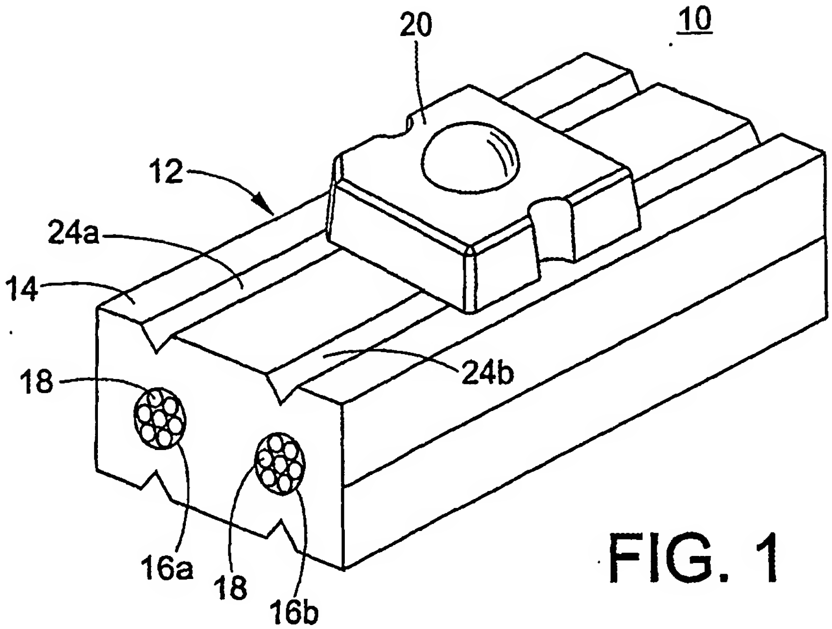

FIG. 1

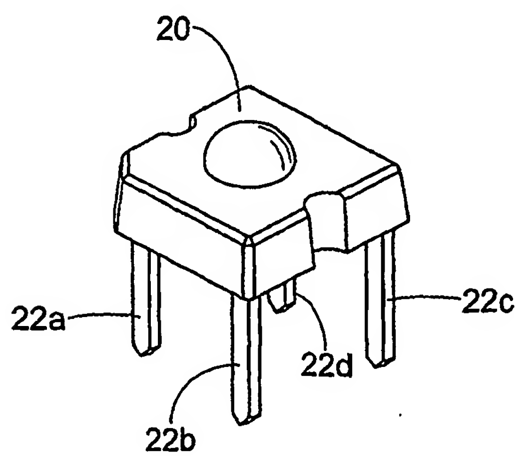

FIG. 2

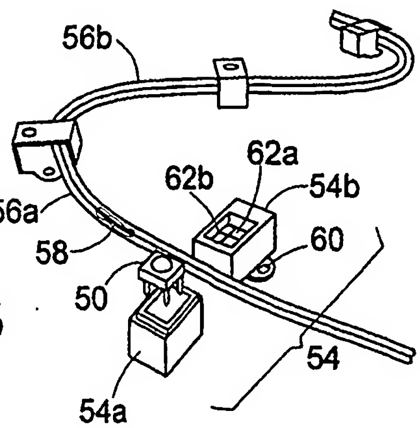

FIG. 3

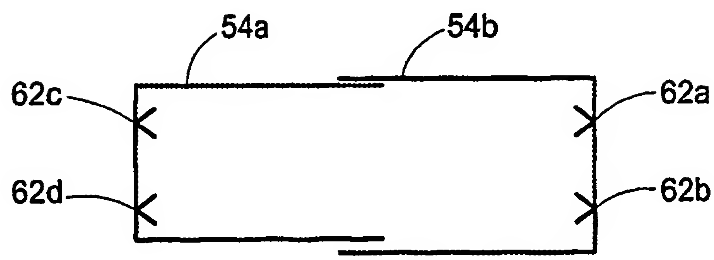

FIG. 4

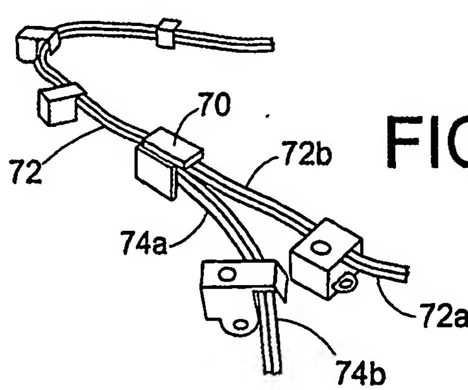

FIG. 5

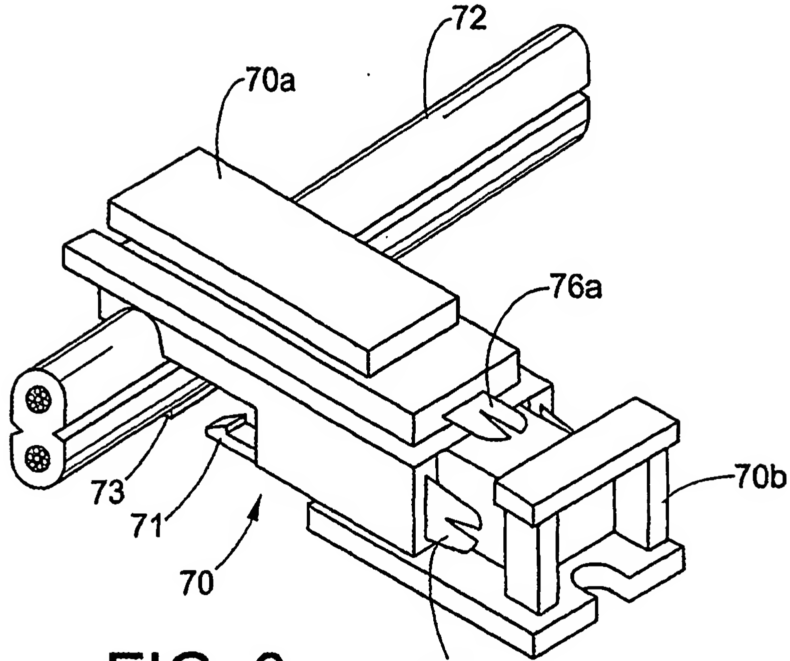

FIG. 6

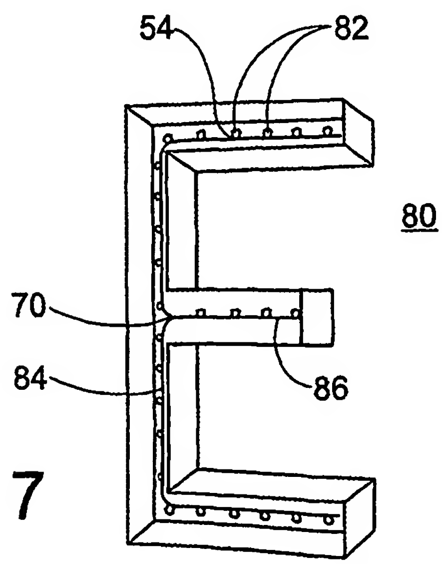

FIG. 7

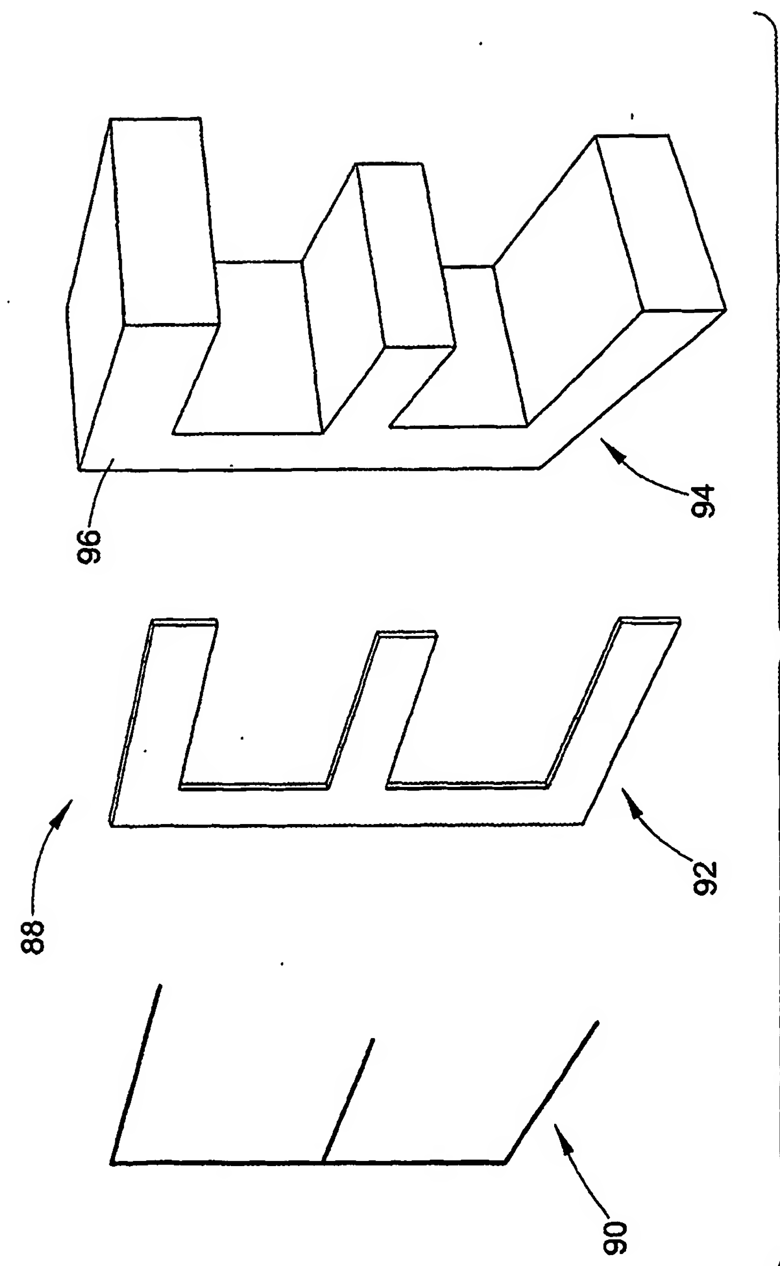

FIG. 8

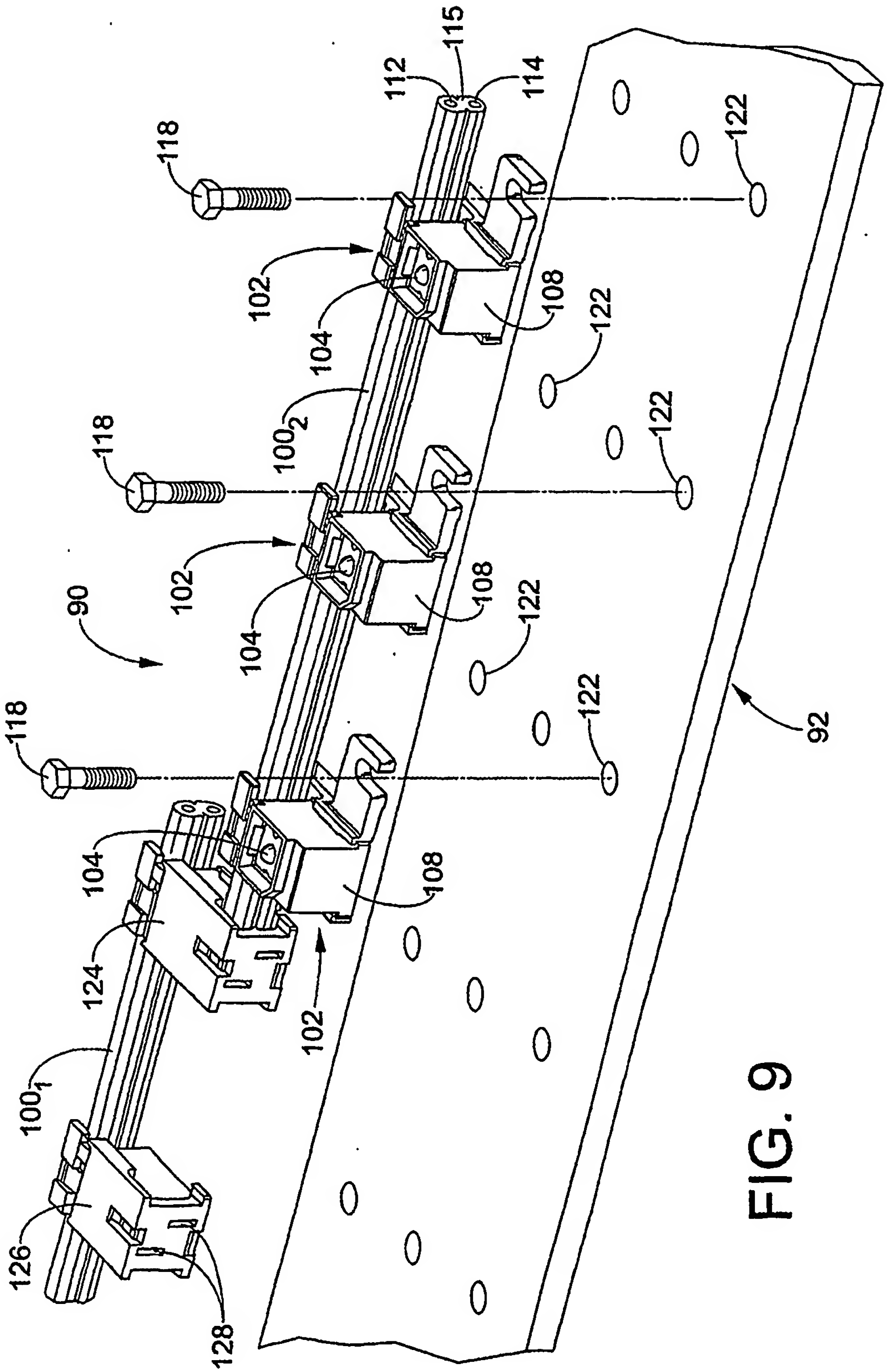
112
115
114
118
122
102
104
108
100_2
118
122
102
104
108
122
90
118
122
104
108
92
124
102
100_1
126
128

FIG. 9

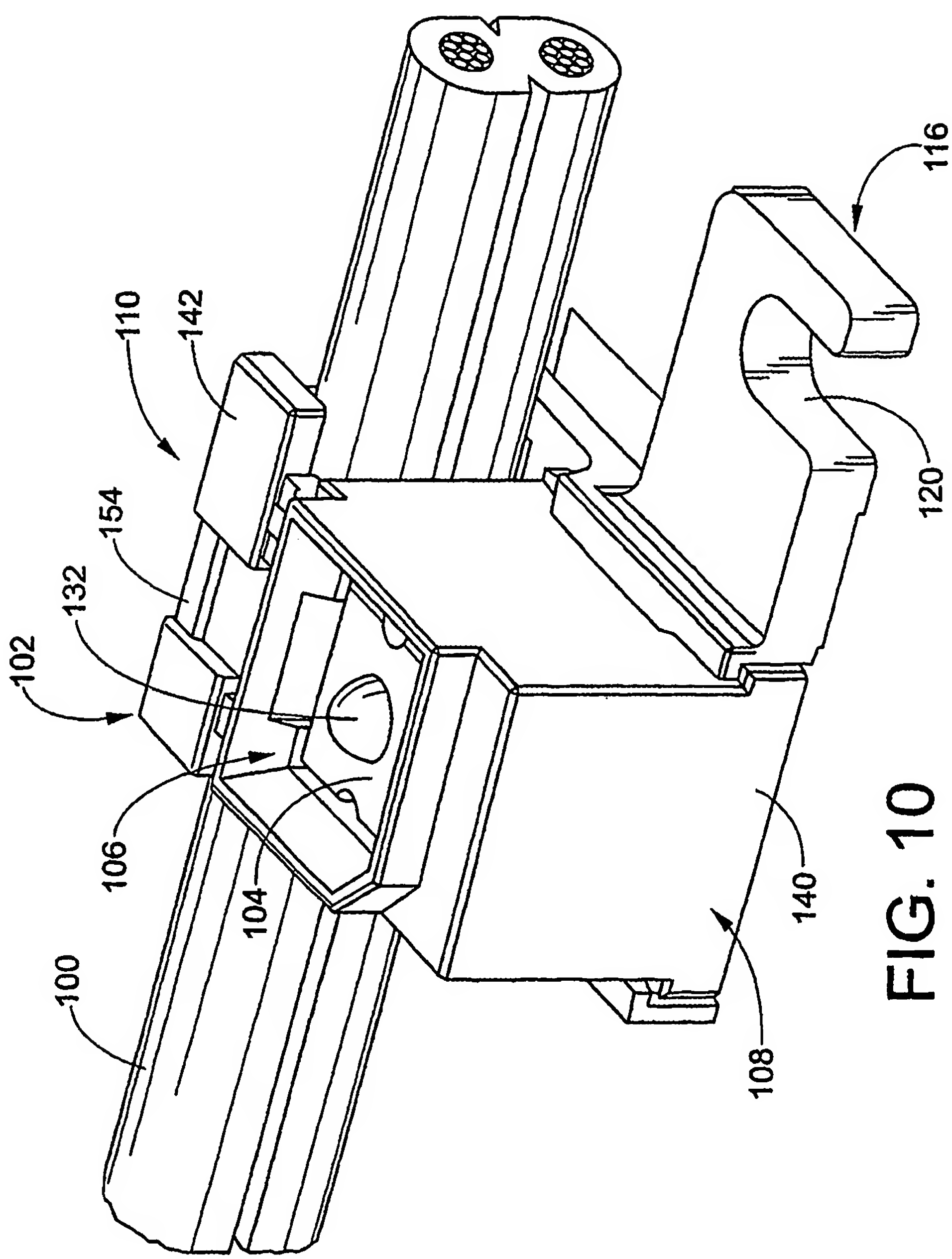

FIG. 10

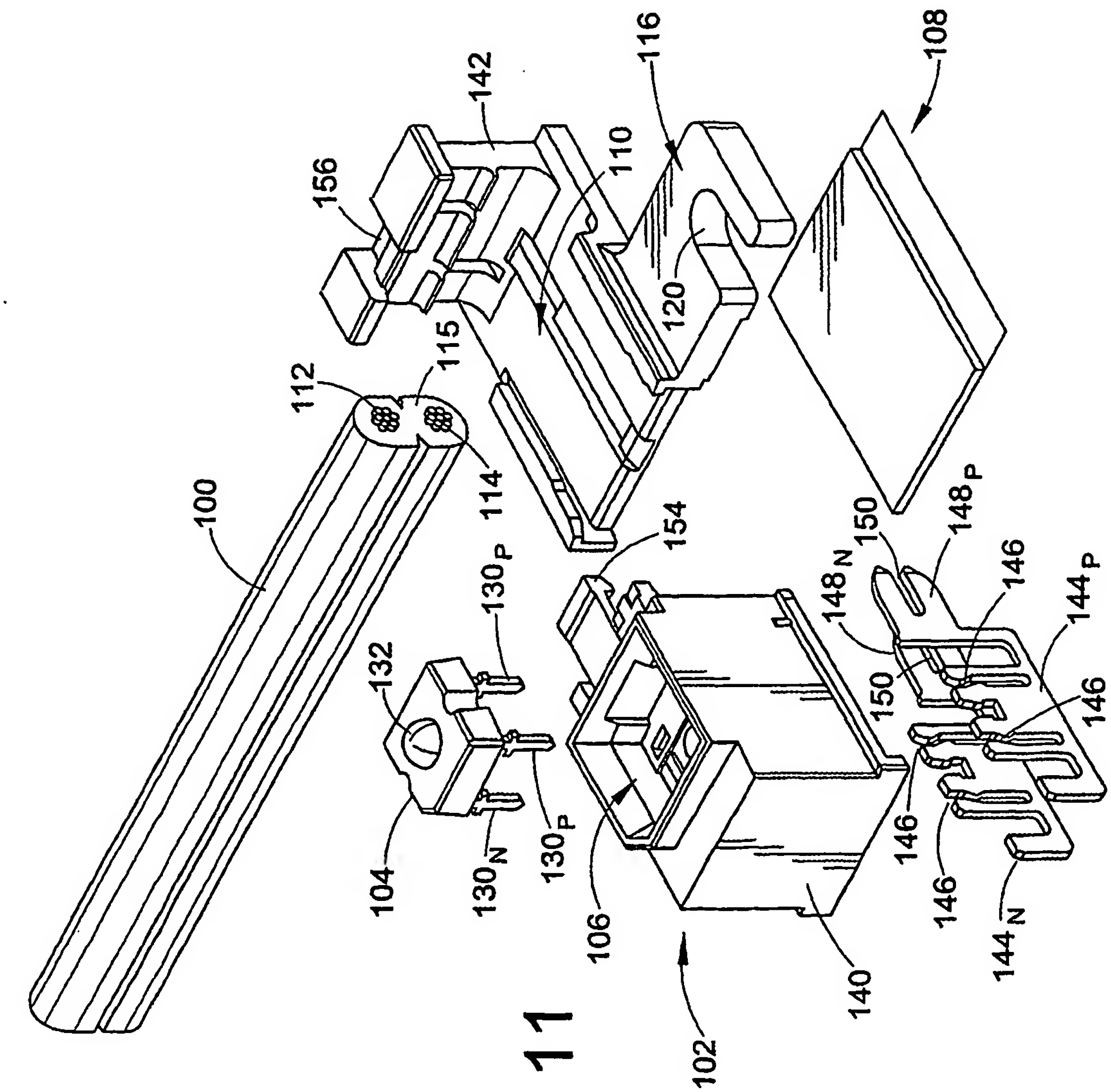
100
112
115
114
156
142
116
110
120
108
132
130_P
130_P
130_N
104
154
106
102
140
148_N
148_P
150
150
146
146
146
146
144_P
144_N

FIG. 11

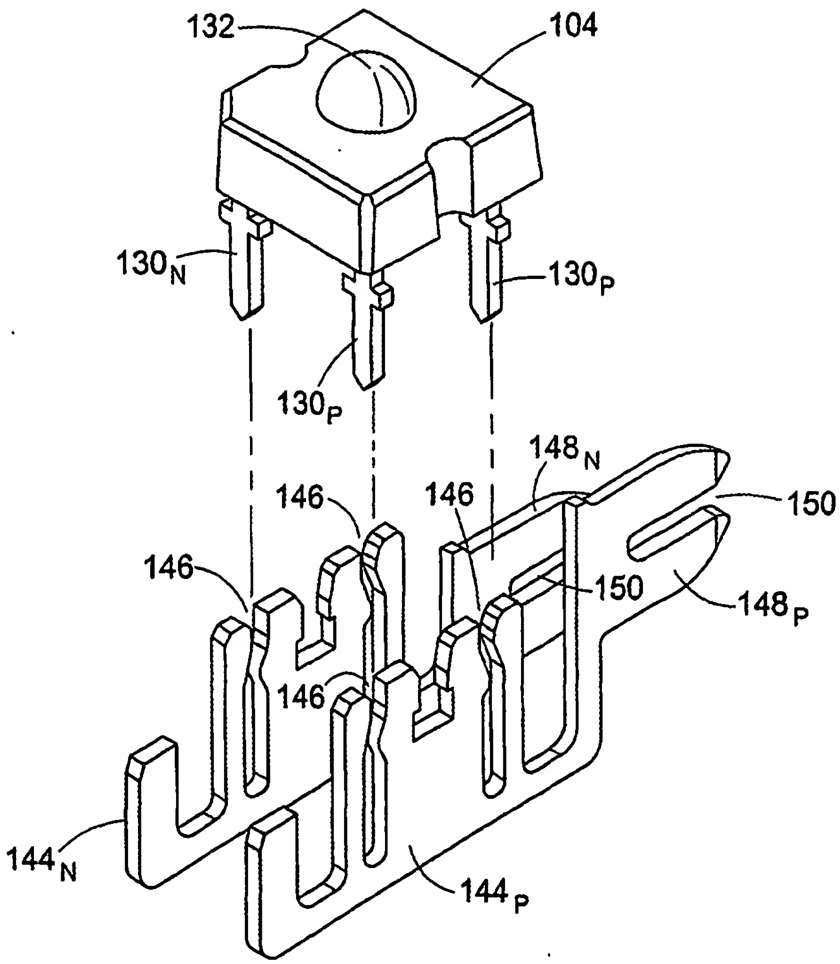
132
104
130_N
130_P
130_P
148_N
146
146
150
146
150
148_P
146
144_N
144_P

FIG. 12

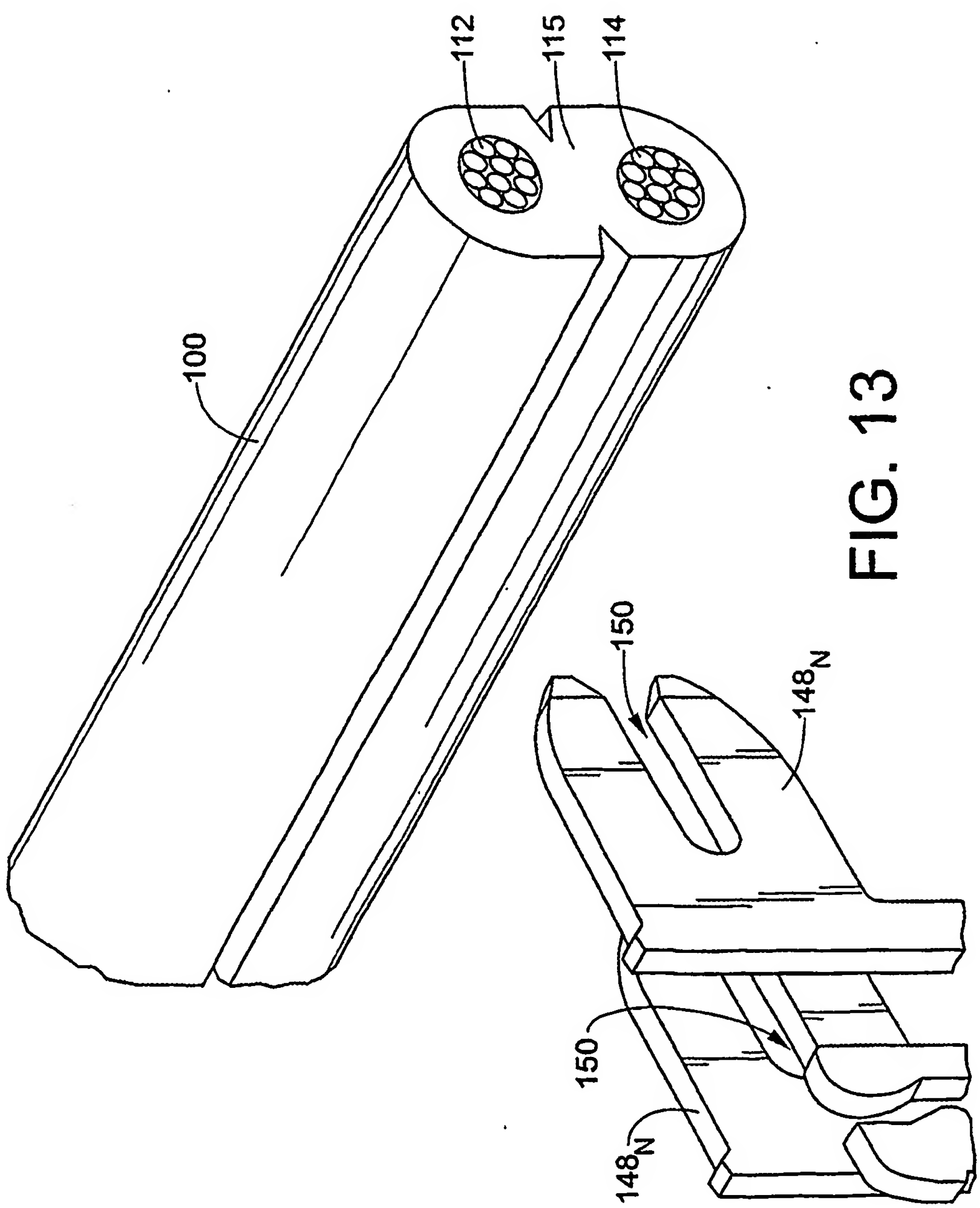

FIG. 13

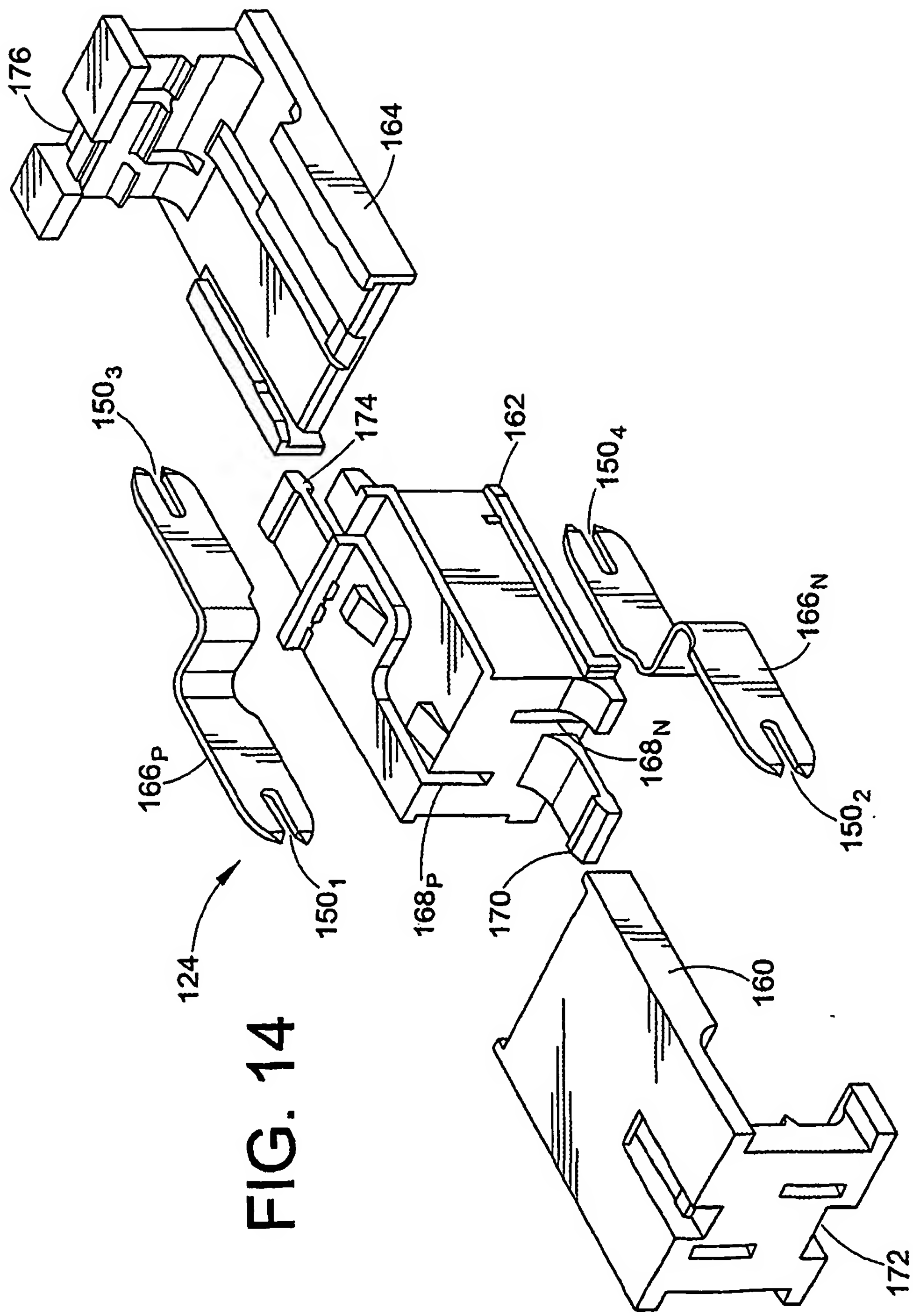
176
164
150_3
174
162
150_4
166_N
168_N
150_2
166_P
150_1
168_P
170
124
160
172

FIG. 14

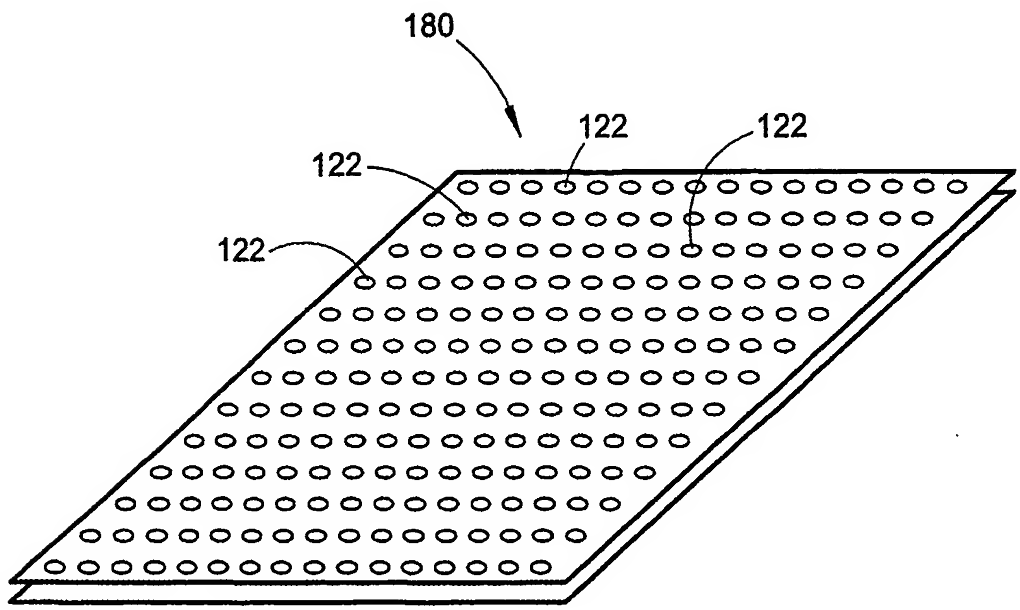

FIG. 15

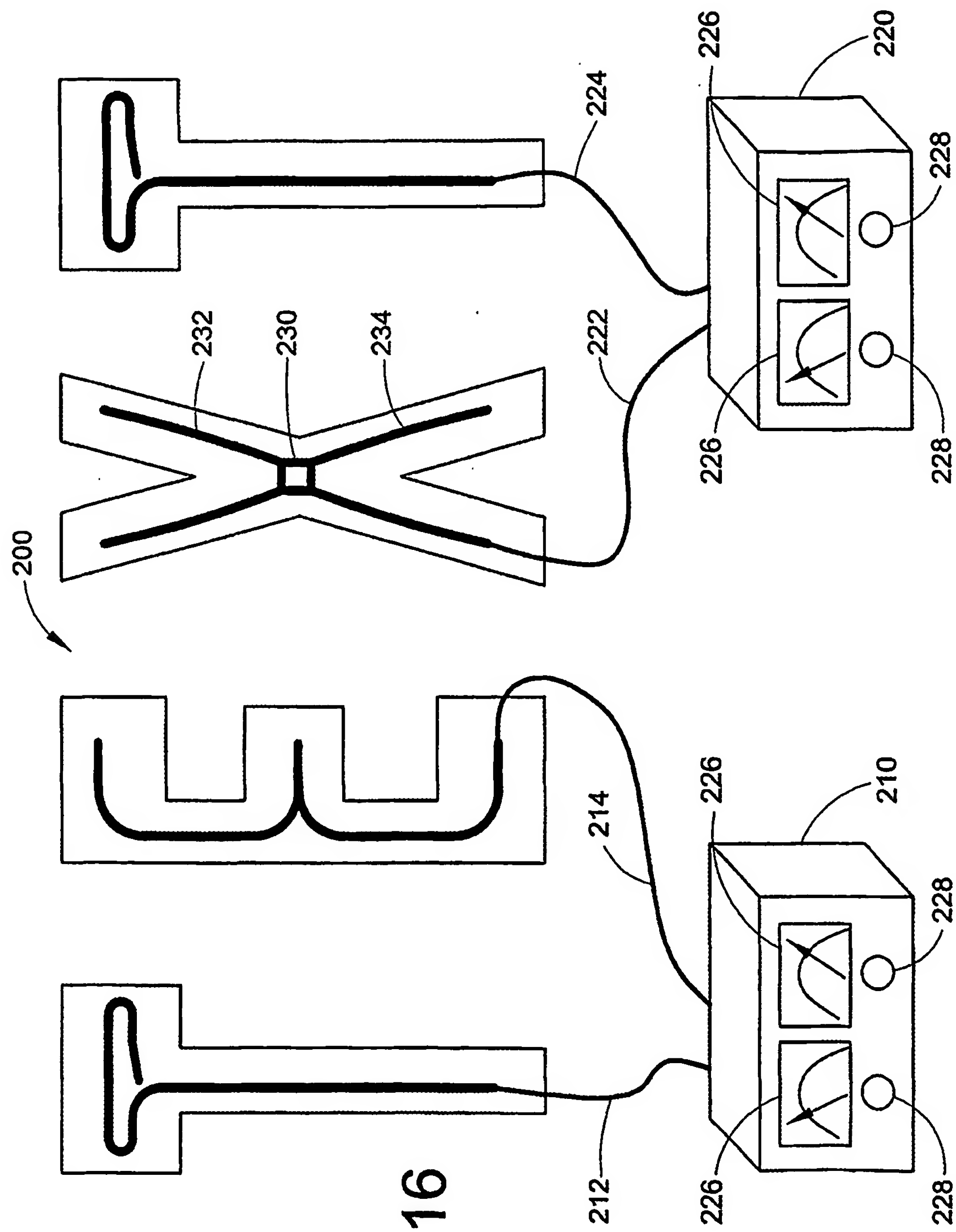
200
232
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FIG. 16